Response Surface Optimization of Osmotic Dehydration Process Parameters for Button Mushroom (*Agaricus bisporus*) - Part I

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Abstract

The effect of brine concentration in the range of 10-20%; solution temperature in the range of 35-55°C and duration of osmosis in the range of 30-60 min on water loss (WL) and salt gain (SG) using the response surface methodology at constant solution to sample ratio of 5/1 (w/w) were investigated for osmotic dehydration of button mushrooms. The study was carried out with three variables and three levels Box-Behnken design to optimize input parameters. The brine concentration, temperature of brine and duration of osmosis with respect to water loss and solid gain were analyzed for linear, quadratic and interaction effects. Second order polynomial models were developed using multiple regression analysis, in addition, the adequacy and accuracy of the fitted models were checked by analysis of variance (ANOVA). The response surfaces and contour maps showing the interaction of process variables provided optimum operation as solution temperature of 44.89°C, brine concentration of 16.53% and duration of osmosis of 47.59 min. At this optimum point, water loss and salt gain were predicted to be 40.55% and 2.98% respectively.

Keywords

Button Mushroom; Osmotic Dehydration; Optimization; Response Surface Methodology; Water Loss; Salt Gain

Introduction

India has with a varied agro-climatic condition, abundance of agricultural waste and work force, making it most suitable for cultivation of all types of mushrooms. Out of more than 2000 varieties of edible mushrooms, about 80 varieties are cultivated experimentally and 4-5 species produced on industrial scale throughout the world. The production of mushroom in India is increasing at fast rate. Although, many species of mushrooms are edible but only three types, *viz* white button mushroom (*Agaricus bisporus*), oyster mushroom (*Pleurotus supp.*) and paddy straw mushroom (*Volvariella volvacea*) are grown commercially in India depending upon the suitability of season with the white button mushroom still contributive to about 90 per cent of total country's production. It is mainly cultivated on the hills, as the requirement of low temperature for its growth; however, with the advent of modern cultivation technology, it is now possible to cultivate this mushroom seasonally under uncontrolled conditions and throughout the year by employment of environmentally controlled conditions. In the last ten years, large numbers of commercials units have been built by the entrepreneurs/farmers throughout the country for the production of button mushrooms which are low calorie foods supplying about 35 calories per 100 grams fresh weight. The carbohydrates in the mushrooms are at a level of 4.5 to 5.0 per cent but in the form of glycogen, chitin and hemicellulose instead of starch. Mushrooms, rich in good quality proteins with lysine and tryptophan that are normally deficient in cereals, are recommended as alternative source of proteins for filling the protein malnutrition gap in the developing countries. The fat contain is as

low as 0.3% but rich in linoleic acid, an essential fatty acid. Cholesterol is absent and in its place ergo-sterol is present which gets converted to vitamin D by the human body. Mushrooms are fairly good source of vitamin C and vitamin B complex, particularly thiamine, riboflavin, niacin, biotin and pantothenic acid. Folic acid and vitamin B_{12} absent in most vegetables are present in the mushrooms which also supply a range of valuable mineral especially potassium and iron. Besides their nutritive value, mushrooms also exhibit certain medicinal properties to treat hepatitis and other diseases of liver and to promote longevity and cosmetic products such as skin whitening agent. Compounds extracted from white button mushroom have anti-fungal and anti-bacterial properties. The high proteins, sterols, macro-elements and low calorie content (i.e. low fat, starch and sugar) make mushroom ideal for prevention of cardiovascular diseases. Thus, they are an ideal food for patients, old people, pregnant women and children.

However, presence of more than 90 per cent moisture content, they are highly perishable and easy to deteriorate immediately after harvest. They develop brown colour on the surface of the cap due to the enzymatic action of phenol oxidase, which results in shorter shelf life. In view of their high perishable nature, the fresh mushrooms have to be processed to extend their shelf life for off-season use by the adoption of appropriate post-harvest technology to process surplus mushrooms into novel value-added products. Thus, it is very important to develop a better method of preservation in order to expand the shelf life besides the maintainance of the quality of button mushroom.

Short term preservation methods like low temperature storage, steeping preservation, irradiation and chemical treatment help to prolong shelf life up to three weeks. Long term preservation methods such as canning, pickling and drying can make the product available throughout the year at reasonable cost. Drying is relatively inexpensive and reduces bulk; thus, contributive to its transportation, handling and storage. Although sun-drying is economical, heated air drying speeds up the process, prevents losses and ensures use of safer drying temperatures as such producing superior product. Vacuum and freeze drying, through the making of better dehydrated products, are energy intensive, sophisticated and therefore, cost prohibitive techniques. Other mechanical drying on commercial scale production of dehydrated vegetables is also in practice in limited scale. All these vegetable drying practices yield poor quality products which are not acceptable for consumers. Application of osmo-convective drying for vegetables improves the quality of final product (dried vegetables). Hence, osmotic dehydration is used as a pre-treatment before hot-air drying of mushrooms because it has the advantage of improvement in nutritional, sensorial and functional aspects of foods, without changing its colour, texture and aroma. Besides, the osmotic dehydration minimizes the thermal damage on colour, flavour and prevents enzymatic browning that is the critical factor on the quality of this kind of mushrooms. The shelf life quality of the final product is better than that without such treatment due to the increase in sugar/acid ratio, the improvement in texture and the stability of the colour pigment during storage. Osmotic dehydration combined with other drying technologies provides an opportunity to produce novel shelf stable types of high quality products for the local as well as export market (Peiro *et al*. 2003).

Response surface methodology (RSM) used to optimize the process parameters for osmotic dehydration of mushroom samples, is a collection of certain statistical techniques to design experiments, build models, evaluate the effects of the factors and search optimal conditions for desirable responses, in which quantitative data from an appropriate experimental design is utilized to determine and simultaneously solve multivariate problems. Equations describing the effect of test variables on responses, determine interrelationships among test variables and represent the combined effect of all test variables in any response. This approach enables an experimenter to make efficient exploration of a process or system. Therefore, RSM has been frequently used in the optimization of food processes (Shi *et al*. 2008).

Limited efforts have so far been made to process button mushrooms into dehydrated product. An expanding interest currently exists for osmo-convective dehydrated button mushroom in the domestic and abroad market. The purpose of the present work was to study the effect of osmotic process parameters viz. brine temperature, brine concentration and duration of osmosis on water loss and solid gain as well as to optimize these parameters to develop higher quality finished product.

Materials and Methods

Mushroom of *Agaricus bisporus* variety with about 87-91 per cent moisture content (wb), was procured on daily basis from All India Co-ordinated Research Project on Mushroom, Rajasthan College of Agriculture, Maharana Pratap University of Agriculture and Technology, Udaipur, Rajasthan. Freshly harvested, firm, mature mushrooms with uniform size, manually sorted and selected as the raw material for all the experiments, were washed to remove adhering impurities; then dried on a blotting paper, and cut into 5±0.5 mm thick slices with the help of sharp stainless steel knife. Common salt (Brand name Tata) used as an osmotic agent, was obtained from the local market of Udaipur. The brine solution of desired concentration was prepared by dissolving the required quantity of salt (w/v) in water. Sample is placed in the hypertonic solution and due to concentration difference; water came out from sample to solution during osmosis. Simultaneously transports of solids took place from solution to sample and vice versa.

Lenart and Flink (1984) were first to define terminologies, for mass transport data during osmotic concentration , which has been used by various researchers such as Kaleemullah *et al.* 2002; Pisalkar *et al.* 2011 and Jain *et al.* 2011 for many food products. Water loss is the net loss of water from food material on an initial mass basis.

$$WL = \frac{W_{si} X_{swi} - W_{s\theta} X_{sw\theta}}{W_{si}} \times 100 \qquad (1)$$

Mass reduction is the net mass reduction of the food material on initial mass basis.

$$WR = \frac{W_{si} - W_{s\theta}}{W_{si}} \times 100 \qquad (2)$$

Solid gain is the net uptake of solids by food material on an initial mass basis.

$$SG = \frac{W_{s\theta}(1 - X_{sw\theta}) - W_{si}(1 - X_{swi})}{W_{si}} \times 100 \qquad (3)$$

Where,

WL = water loss (g water per 100 g initial mass of sample)

WR = mass reduction (g mass per 100 g initial mass of sample)

SG = solid gain (g solids per 100g initial mass of sample)

W_{si} = initial mass of sample, g

$W_{s\theta}$ = mass of the sample after time θ, g

X_{swi} = water content as a fraction of the initial mass of the sample

$X_{sw\theta}$ = water content as a fraction of the syrup at time θ

Box-Behnken design of three variables and three levels including seventeen experiments formed by five central points was used (Box and Behnken, 1960). This design fulfilled almost all requirements needed for optimization of the osmotic dehydration process prior to convective drying. The osmotic dehydration was assumed to be affected mainly by three independent variables (factors), *viz.*, brine temperature (T) (35-55°C), salt concentration (C) (10-20%) and duration of osmosis (θ) (30-60 min). All these variables were closely controlled and accurately measured during experimentation. The exact mathematical representation of the function (*f*) is either unknown or extremely complex. However, second order polynomial equation of the following form was assumed to relate the response and the factors as

$$Y_k = \beta_{ko} + \sum_{i=1}^{i=3} \beta_{ki} x_i + \sum_{i=1}^{i=3} \beta_{kii} x_i^2 + \sum_{i=1}^{i=2} \sum_{j=i+1}^{j=3} \beta_{kij} x_i x_j \qquad (4)$$

Where, Y_k is response (i. e. water loss or salt gain) β_{ko}, β_{ki}, β_{kii} and β_{kij} are coefficients and x_i and x_j are the coded independent variables that are linearly related to *T*, *C* and. In practice, the levels of the independent variables change from one application to another. Therefore, the general designs are given in terms of standardized coded variables (*xi*) which in any particular application are linearly related to *ri* by the following equation:

$$x_i = \frac{(r_i - \bar{r}_i)}{d_i} \qquad (5)$$

Where, r_i = actual value in original units,

$\bar{r}_i$ = mean of high and low levels of r_i

d_i = spacing between low and high levels of r_i.

In present study, n = 2 and m = 3 and hence Eqn. (4) can be written as

$$Y_k = f_k(T, C, \theta) \qquad (6)$$

Where, T = brine solution temperature in ^{o}C, C = salt concentration in %, θ = duration of osmosis in min, Y_k = water loss or salt gain in per cent, during osmotic

dehydration of mushroom slices. Hence, Eqn. (4) takes the following form as

$$Y_k = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{33} x_3^2 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3 \qquad （6）$$

Response surface methodology (RSM) was applied to the experimental data using the package, design-expert version 8.0.6 software (Stat-Ease Inc, Minneapolis, USA).

Results and Discussions

The process parameters (brine concentration, solution

temperature and duration of osmosis) were optimized for maximum water loss and optimum salt gain (2.98%). This optimum salt gain was decided by taking sensory evaluation of osmo-convectively dried mushroom samples having different salt gain levels. Values of various responses (water loss and salt gain) at different experimental combinations for coded variables are given in Table 1.

TABLE 1 EXPERIMENTAL DATA FOR THREE-VARIABLES AND THREE LEVELS RESPONSE SURFACE ANALYSIS

S. No.	Brine Temp.,	Brine Conc.,	Duration of osmosis, min	Water loss, %	Salt gain, %
1	(1)55	(1)20	(0)45	44.93	3.24
2	(1)55	(-1)10	(0)45	36.38	1.03
3	(-1)35	(1)20	(0)45	39.70	2.56
4	(-1)35	(-1)10	(0)45	29.92	0.59
5	(1)55	(0)15	(1)60	43.92	2.90
6	(1)55	(0)15	(-1)30	34.23	2.24
7	(-1)35	(0)15	(1)60	37.09	2.34
8	(-1)35	(0)15	(-1)30	29.54	1.73
9	(0)45	(1)20	(1)60	45.04	3.03
10	(0)45	(1)20	(-1)30	35.51	2.22
11	(0)45	(-1)10	(1)60	33.69	1.06
12	(0)45	(-1)10	(-1)30	26.18	0.33
13	(0)45	(0)15	(0)45	38.05	2.57
14	(0)45	(0)15	(0)45	38.44	2.64
15	(0)45	(0)15	(0)45	38.27	2.64
16	(0)45	(0)15	(0)45	38.55	2.79
17	(0)45	(0)15	(0)45	38.60	2.82

Effect of Variables on Water Loss

The variation in water loss by changing brine temperature, concentration and osmosis duration has been presented in Table 1. A second order polynomial equation [Eqn. (6)] was fitted with the experimental data presented in Table 1. Eqn. (7) gave the predicted water loss, per cent as a function of brine temperature, concentration and duration of osmosis. This equation was obtained using step-down regression method where factors with F-values less than one were rejected as described by Snedecor and Cochran (1967). The data for water loss were analysed for stepwise regression

analyses as shown in Table 2. The quadratic model was fitted to the experimental data and statistical significance for linear, quadratic and interaction terms was calculated for water loss as shown in Table 2. The R^2 value calculated by least square technique was found to be 0.997 showing good fit of model to the data. The model F value of 377.07 implied that the model was significant ($P < 0.01$). The linear terms (T, C and θ) are significant ($P < 0.01$). The 'lack of fit F value' of 5.08 was insignificant, which indicated that the developed model was adequate to predict the water loss. Moreover the predicted R^2 of 0.983 was in reasonable agreement with adjusted R^2 of 0.995.

Therefore this model could be used to navigate the design space.

High value of coefficient of determination (R^2 = 0.997) obtained for response variable indicated that the developed model for water loss accounted for and adequately explained 99.7 per cent of the total variation. The result of analysis of variance of Eqn. (7) indicated that the linear terms of brine temperature, concentration and duration of osmosis were highly significant at 5 per cent level (Table 2). The quadratic terms of concentration of brine and duration of osmosis were also highly significant at 5 per cent level while interaction terms of temperature of brine and duration of osmosis as well as concentration of brine and duration of osmosis were significant at 1 per cent level.

TABLE 2 ANALYSIS OF VARIANCE FOR WATER LOSS DURING OSMOTIC DEHYDRATION OF MUSHROOM SAMPLE

Source	Sum of squares	df	Mean sum of squares	F value
Model	435.01	7	62.14	377.07*
T	67.34	1	67.34	408.58*
C	190.22	1	190.22	1154.20*
θ	146.89	1	146.89	891.27*
T θ	1.14	1	1.14	6.95**
C θ	1.02	1	1.02	6.19**
C^2	3.11	1	3.11	18.87*
θ^2	24.23	1	24.23	147.03*
Residual	1.48	9	0.16	
Lack of Fit	1.28	5	0.26	5.08NS
Pure Error	0.20	4	0.050	
R^2	0.997	16		
Adj. R^2	0.995			
C.V., %	1.10			

* Significant at 5 % Level, ** Significant at 1 % Level and NS - Non significant

The comparative effect of each factor on water loss was observed by the F values in the ANOVA (Tables 2) and also by the magnitudes of coefficients of developed equation. The F values indicated that concentration of brine was the most influencing factor followed by duration of osmosis; in addition, temperature of brine was least effective over water loss which in real terms of brine temperature, concentration and duration of osmosis can be given by

$$WL = 19.58 + 0.13T + 1.70C + 0.98\theta + 3.57 \times 10^{-3}\,T\theta + 6.73 \times 10^{-3}\,C\theta - 3.43 \times 10^2 C^2 - 1.06 \times 10^{-2}\theta^2 \qquad (7)$$

The linear positive terms [Eqn. (7)] indicated that water loss rose with increase in brine temperature, brine concentration and duration of osmosis. The presence of positive interaction terms between brine temperature and duration of osmosis as well as brine concentration and duration of osmosis indicated that increase in their levels added water loss. The negative values of quadratic terms of brine concentration and duration of osmosis indicated that higher values of these variables further reduced water loss.

To visualize the combined effect of two variables on the water loss, the response surface and contour plots (Fig 1 A, B and C) were generated for the fitted model as a function of two variables while keeping third variable at its central value. The water loss increased rapidly in the early stages of osmosis, after which the rate of water loss from mushroom sample into salt solution gradually slowed down with time. Rapid removal of water in early stages of osmosis has been reported for litchi (Vishal *et al*. 2009), aloe-vera (Pisalkar *et al*. 2011), (Uddin *et al*. 2004), papaya (Jain *et al*. 2011), mushroom (Kar and Gupta 2001; Murumkar *et al*. 2007; Shukla and Singh 2007), etc.

Higher temperatures seem to accelerate water loss (Fig. 1 A and B) through swelling and plasticizing of cell membranes as well as the better water transfer

characteristics on the product surface due to lower viscosity of the osmotic medium (Uddin *et al.* 2004). Water loss increased with concentration of salt (Fig. 1 A and C) as well as with duration of osmosis (Fig. 1 B and C) over the entire osmotic dehydration process. In the osmosis of other fruits and vegetables, also such effect has been observed (Pokharkar and Prasad 2002; Kar and Gupta 2001and Jain *et al.*2011).
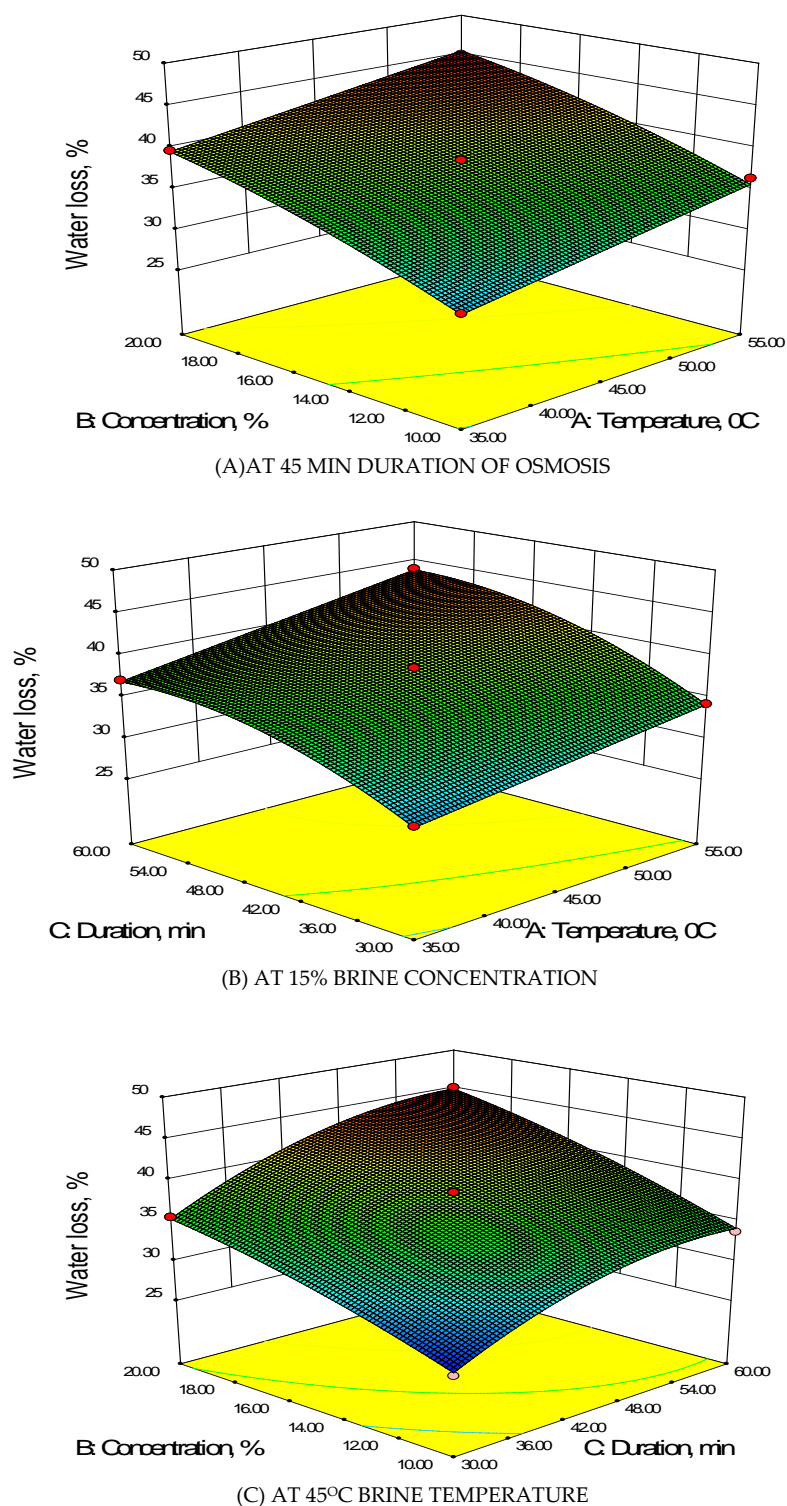

(A)AT 45 MIN DURATION OF OSMOSIS

(B) AT 15% BRINE CONCENTRATION

(C) AT 45°C BRINE TEMPERATURE

FIG. 1 CONTOUR AND RESPONSE SURFACE SHOWING THE EFFECT OF TEMPERATURE, CONCENTRATION AND DURATION OF OSMOSIS ON WATER LOSS DURING OSMOTIC DEHYDRATION

Effect of Variables on Salt Gain

The salt gain during the osmotic dehydration was found to be dependent on the brine temperature, concentration and duration of osmosis (Table 1). A second order polynomial equation [Eqn. (8)] was fitted with the experimental data presented in Table 1. Eqn. (8) gave the predicted salt gain, per cent as a function of brine temperature, concentration and duration of osmosis. This equation was obtained using step-down regression method where factors with F-values less than one were rejected as described by Snedecor and Cochran (1967). The data for salt gain were analyzed for stepwise regression analysis as shown in Table 3. The quadratic model was fitted to the experimental data and statistical significance for linear and quadratic terms was calculated for salt gain as shown in Table 3. The R^2 value calculated by least square technique was found to be 0.993 showing good fit of model to the data. The model F value of 245.41 implied that the model was significant ($P < 0.01$). The linear terms (T, C and θ) were significant ($P < 0.01$). The lack of fit was insignificant, which indicated that the developed model was adequate to predicate the response. Moreover the predicted R^2 of 0.982 was in reasonable agreement with adjusted R^2 of 0.989. This revealed that the insignificant terms have not been included in the model. Therefore this model could be used to navigate the design space.

TABLE 3 ANALYSIS OF VARIANCE FOR SALT GAIN DURING OSMOTIC DEHYDRATION OF MUSHROOM SAMPLE

Source	Sum of squares	df	Mean sum of squares	F value
Model	12.54	6	2.09	245.41*
T	0.60	1	0.60	70.42*
C	8.08	1	8.08	949.16*
θ	0.99	1	0.99	115.94*
T^2	0.04	1	0.04	4.68^{NS}
C^2	2.30	1	2.30	270.66*
θ^2	0.36	1	0.36	42.24*
Residual	0.09	10	0.009	
Lack of Fit	0.04	6	0.006	0.56^{NS}
Pure Error	0.05	4	0.012	
Cor Total	12.62	16		
R^2	0.993			
Adj. R^2	0.989			
Pred. R^2	0.982			
C.V. %	4.27			

* Significant at 5% level, NS - Non significant

High value of coefficient of determination (R^2=0.993) obtained for response variable indicated that the developed model for salt gain accounted for and adequately explained 99.3 per cent of the total variation. The result of analysis of variance indicated that the linear terms of brine temperature, concentration and duration of osmosis were highly significant at 5 per cent level (Table 3). The presence of quadratic terms of concentration of brine and duration of osmosis indicated curvilinear nature of response surface. The quadratic terms of concentration of brine and duration of osmosis were also highly significant at

5 per cent level while quadratic term of temperature was insignificant.

The comparative effect of each factor on salt gain could be observed by F values in the ANOVA (Table 3) and also by the magnitudes of the coded variables. The F values indicated that concentration of brine was the most influencing factor followed by duration of osmosis and temperature of brine was least effective over salt gain which in real terms of brine temperature, concentration and duration of osmosis is given by

$$SG = -13.87 + 0.11T + 1.09C + 0.14\theta - 9.73 \times 10^{-4}T^2 - 2.96 \times 10^{-2}C^2 - 1.29 \times 10^{-3}\theta^2 \qquad \dots 8$$

The linear positive terms [Eqn. (8)] indicated that salt gain increased with increase in brine temperature, concentration and duration of osmosis. The negative values of quadratic terms of temperature and concentration of brine and duration of osmosis indicated that higher values of these variables further reduced salt gain. To visualize the combined effect of two variables on the salt gain, the response surface and contour plots (Fig. 2 A, B and C) were generated for the fitted model as a function of two variables while keeping third variable at its central value.

The salt gain increased rapidly in the early stages of osmosis after which the rate of salt gain from brine solution to mushroom sample slowed down with duration. The salt gain was found to increase with temperature (Fig. 2 A and B). As it was explained for water loss, temperature has an effect on the cell membrane permeability that could allow solute to enter by loosing its selectivity. Decrease of solution viscosity at higher temperature may influence salt gain due to fact that lower viscosity decreases the resistance to diffusion of solutes into the sample (food product) tissue. The rise of concentration of the brine solution also led to increase in salt gain (Fig. 2 A and C) probably due to an increase of osmotic pressure gradient and consequent loss of functionality of cell plasmatic membrane that allowed solute to enter.

It was observed from these figures (Fig 2 and 3) that the moisture loss as well as the solid gain increased non-linearly with time at all concentrations. Both moisture loss and solid gain were faster in the initial period of osmosis and then the rate decreased. This was because osmotic driving potential for moisture as well solid transfer would keep on decreasing with time as the moisture kept moving from sample to solution and the solids from solution to sample. Further progressive solid uptake would result in the formation of high solid sub surface layer, which would interface with the concentration gradients across the sample solution interface and be set as barrier against removal of water and uptake of solid (Hawkes and Flink, 1978). Besides, rapid loss of water and uptake of solids near the surface in the beginning may result in structural changes leading to compaction of this surface layers and increased mass transfer resistance for water and solids (Lenart and Flink 1984). Similar trends have been reported for other fruits and vegetables during osmosis (Pokharkar and Prasad 2002; Ghosh *et al.* 2006 and Alam *et al.* 2010)
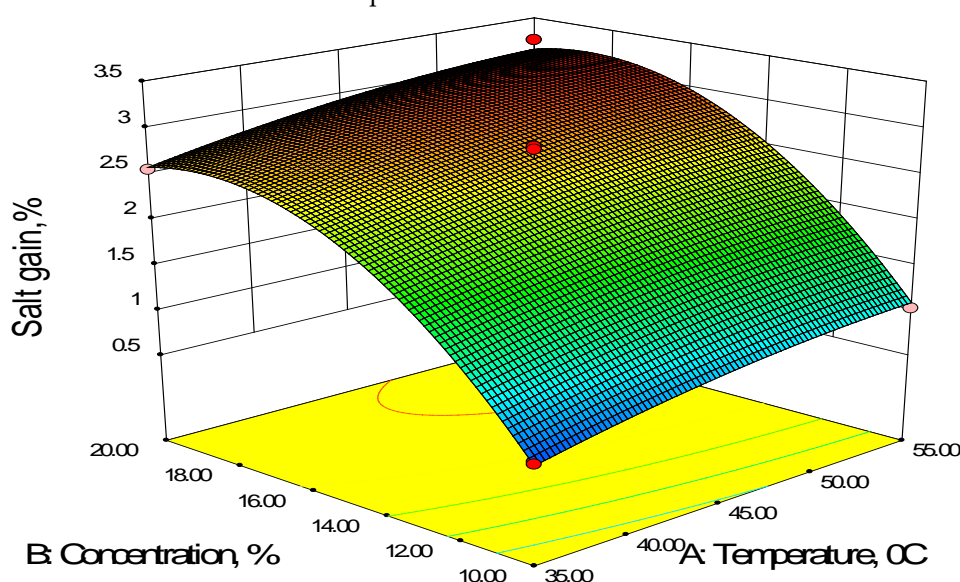
(A) AT 45 MIN DURATION OF OSMOSIS
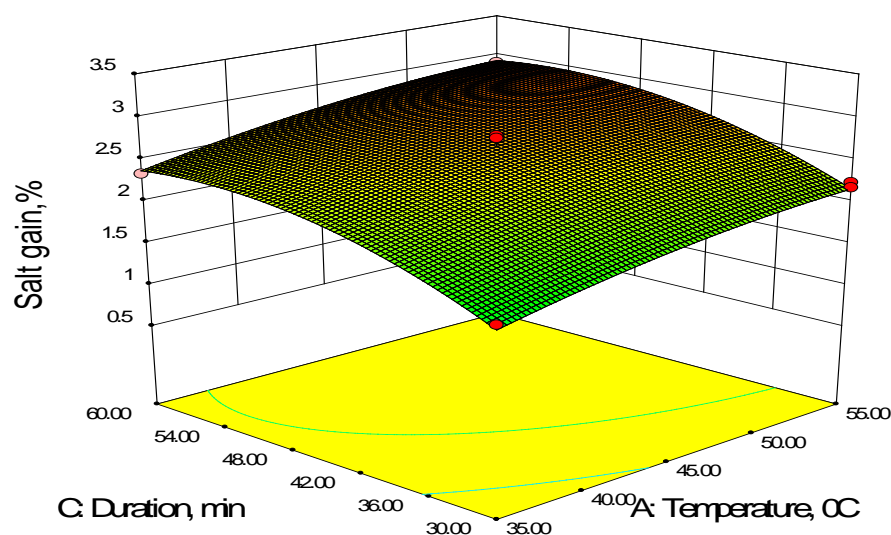
(B) AT 15% BRINE CONCENTRATION
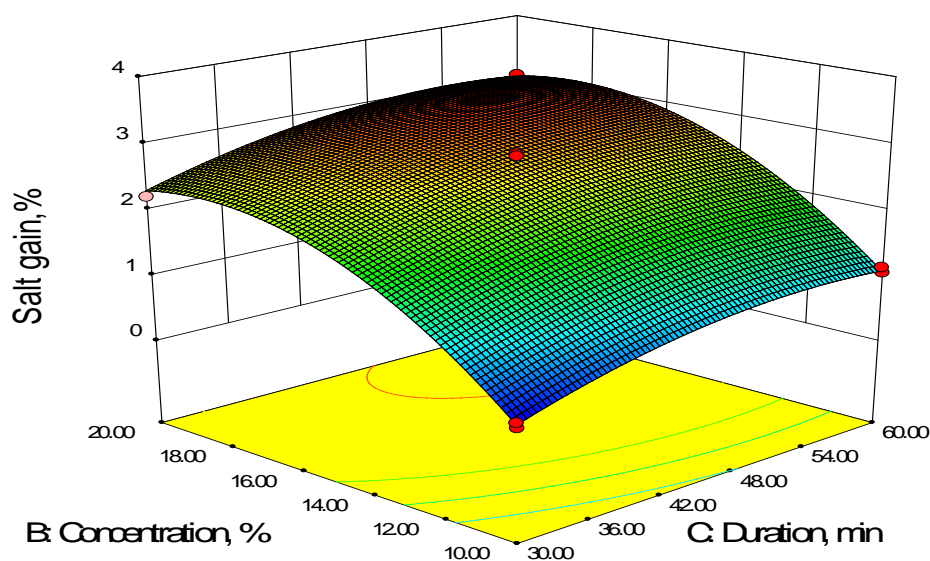
(C) AT 45°C BRINE TEMPERATURE

FIG. 2 CONTOUR AND RESPONSE SURFACE SHOWING THE EFFECT OF TEMPERATURE, CONCENTRATION AND DURATION OF OSMOSIS ON SALT GAIN DURING OSMOTIC DEHYDRATION

Optimization of Osmotic Dehydration of Mushroom

Numerical multi response optimization technique was carried out for the process parameters of the osmotic dehydration of mushroom sample. Design of expert version 8.0.6 of the stat-ease software was used for simultaneous optimization of the multiple responses. The constraints were set such that the selected variables (T, C and θ) would be the minimum from economical point of view for the most important product attribute and close to the optimum for the others (Jain *et al*., 2011). The main criteria for constraints optimization were maximum possible water loss and targeted salt gain of 2.98 percent as

most important quality (saltiness) attribute (Ade-Omowaye *et al.* 2002; Tonon *et al.* 2007 and Shi *et al.* 2008). The desired goals for each factor and response are shown in Table 4. The process parameters for osmotic dehydration process were numerically optimized for desirability function having equal importance (+) to all the three process parameters and equal importance (+++++) to two responses. The goal setting began at a random starting point and proceeded up the steepest slope on the response surface for a maximum value of water loss and targeted value of salt gain.

TABLE 4 OPTIMIZATION CRITERIA FOR DIFFERENT PROCESS VARIABLES AND RESPONSES FOR OSMOTIC DEHYDRATION OF MUSHROOM SAMPLE

Parameter	Goal	Lower limit	Upper limit	Importance	Optimized value
Temperature, ᵒC	minimize	35	55	1	44.89
Concentration, %	minimize	10	20	1	16.53
Duration, min	minimize	30	60	1	47.59
Water loss, %	maximize	26.18	45.04	5	40.55
Salt gain, %	target = 2.98	0.33	3.24	5	2.98

Table 4 also shows the software generating optimum conditions of independent variables with the predicted values of responses. The optimum values of process variables obtained by numerical optimization were taken as follows:
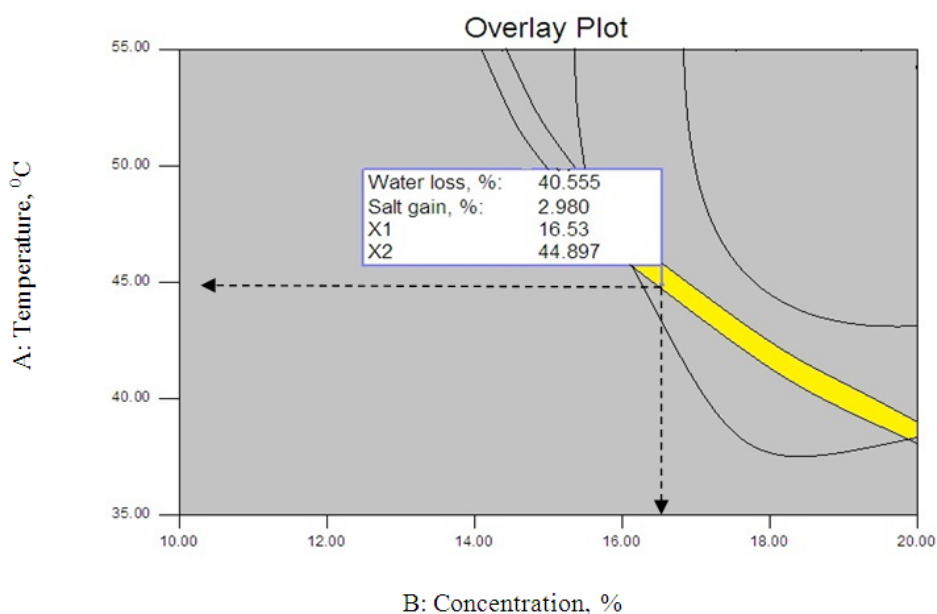
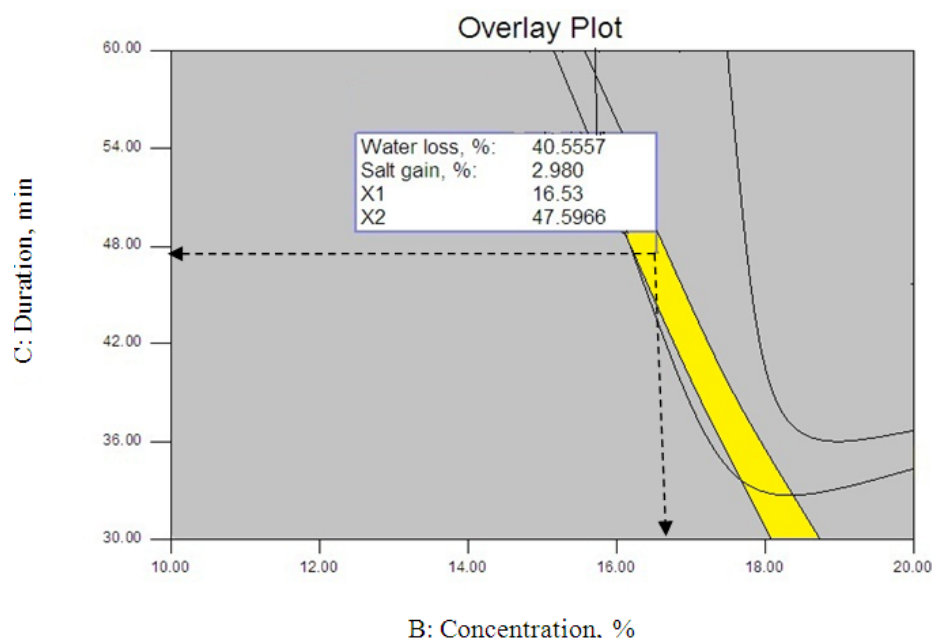Temperature of brine, ᵒC　　: 44.89　≈　45

Concentration of salt, %　　: 16.53　≈　17

Duration of osmosis, min　　: 47.59　≈　48

A graphical multi response optimization technique was adapted to determine the workable optimum conditions for the osmotic dehydration of mushroom sample. The contour plots for all responses were superimposed and regions that best satisfied all the constraints were selected as optimum conditions. The criteria for constraint optimization are already given in Table 4. These constraints resulted in feasible zone of the optimum solutions (yellow coloured area in the superimposed contour plots). Superimposed contour plots having common superimposed area for all responses for osmotic dehydration of mushroom sample are shown in Fig. 3.

（A）FOR DURATION OF OSMOSIS = 47.59 Min

Overlay Plot

Water loss, %:	40.5557
Salt gain, %:	2.980
X1	16.53
X2	47.5966

(B) AT TEMPERATURE OF BRINE = 44.89°C

FIG. 3 SUPERIMPOSED CONTOURS FOR WATER LOSS (%) AND SALT GAIN (%) FOR OSMOTIC DEHYDRATION OF MUSHROOM SAMPLE AT VARYING (A) CONCENTRATION OF SALT AND TEMPERATURE OF BRINE AND (B) CONCENTRATION OF SALT AND DURATION OF OSMOSIS

Conclusions

The RSM was effective in optimization of process parameters for osmotic dehydration of mushroom slices in osmotic aqueous solution of salt having concentration in the range of 10 to 20%, solution temperature 35 to 55°C and immersion time 30 to 60 min. The regression equation obtained can be used for optimum conditions for desired responses within the range of conditions applied to the study. Graphical techniques, in connection with RSM, aided in locating optimum operating conditions which were experimentally verified and proven to be adequately reproducible. Optimum solutions obtained by numerical optimization were 16.53% brine concentration, 44.89°C osmotic solution temperature and 47.59 min of immersion time to get maximum possible water loss (40.55%). The model equation for the response variables predicted values under the identified optimum conditions which were experimentally verified to be in general agreement in the model.

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